Not to be cited without
permission of the authors[1]

Ne pas citer sans
autorisation des auteurs[1]

DFO Atlantic Fisheries
Research Document 94/36

MPO Pêches de l'Atlantique
Document de recherche 94/36

Assessment of Cod in Division 4X

by

S. Gavaris, D. Clark and P. Perley
Department of Fisheries and Oceans
Biological Station
St. Andrews, New Brunswick

[1]This series documents the scientific basis for the evaluation of fisheries resources in Atlantic Canada. As such, it addresses the issues of the day in the time frames required and the documents it contains are not intended as definitive statements on the subjects addressed but rather as progress reports on ongoing investigations.

Research documents are produced in the official language in which they are provided to the secretariat.

[1]La présente série documente les bases scientifiques des évaluations des ressources halieutiques sur la côte atlantique du Canada. Elle traite des problèmes courants selon les échéanciers dictés. Les documents qu'elle contient ne doivent pas être considérés comme des énoncés définitifs sur les sujets traités, mais plutôt comme des rapports d'étape sur les études en cours.

Les Documents de recherche sont publiés dans la langue officielle utilisée dans le manuscrit envoyé au secrétariat.

ABSTRACT

Landings of cod from Division 4X have fluctuated since 1970 between 33,000t and the low 1993 value of 16,000t. The 1993 fishery was supported to a great extent by the 1990 and 1989 year classes, with age 2 cod making up a higher proportion of the catch than usual. The age 4+ survey index for 1993 is the lowest on record, while the survey index for age 3 is about average.

The adaptive framework was used to calibrate the sequential population analysis with the research survey results. The SPA results indicate that age 3+ biomass has risen slightly from the record low level of 1992 due to the recruitment of the 1990 year class, which, although only of average size for the entire time series, is the strongest since the 1987 cohort. Fishing mortality, though down from the 1992 level, still exceeds twice $F_{0.1}$ and has likely resulted in lost yield due to capture of fish before their full growth potential has been realized.

Yield projections show that the expected catch of 13,000 t in 1994 will result in a fishing mortality of about 0.57. The projected $F_{0.1}$ yield for 1995 is about 6,300t, or 4,400t if allowance is made for the retrospective pattern. With no preliminary indications of good recruitment following the 1990 year class, lower exploitation will prolong the contribution of available fish to the fishery and help maintain a higher spawning biomass.

RESUME

Depuis 1970, les débarquements de morue en provenance de la division 4X ont fluctué entre 33 000 t et le seuil de 16 000 t atteint en 1993. La pêche de 1993 a été alimentée dans une large mesure par les classes d'âge de 1990 et 1989, la morue d'âge 2 représentant une plus grande proportion des prises. L'indice de l'abondance des morues d'âge 4+ établi d'après les relevés de recherche de 1993 est le plus bas jamais enregistré, tandis que celui qui porte sur les morues d'âge 3 correspond à peu près à la moyenne.

On a étalonné l'analyse séquentielle de population d'après les résultats des relevés de recherche, au moyen du modèle ADAPT. Les résultats obtenus révèlent que la biomasse des morues d'âge 3 + a augmenté légèrement depuis le minimum record enregistré en 1992, cela à cause du recrutement de la classe d'âge de 1990, qui, quoique de taille moyenne par rapport à toute la série chronologique, est la plus forte depuis la cohorte de 1987. La mortalité par pêche est en recul comparativement à celle de 1992, mais est encore de plus du double de $F_{0.1}$; elle s'est vraisemblablement traduite par une perte de rendement due à la capture du poisson avant que celui-ci ait pu atteindre sa taille optimale.

Les projections de rendement révèlent que les prises de 13 000 t attendues en 1994 correspondront à une mortalité par pêche d'environ 0,57. Le rendement $F_{0.1}$ projeté pour 1995 est d'environ 6 300 t, ou 4 400 t si l'on tient compte de l'effet rétroactif. En l'absence d'indice préliminaire de bon recrutement depuis la classe d'âge de 1990, une exploitation plus faible prolongera l'apport du poisson disponible à la pêche et permettra de maintenir à un niveau élevé la biomasse de reproducteurs.

DESCRIPTION OF FISHERY

Landings of cod from Division 4X (including the Canadian portion of Division 5Y; Fig. 1) averaged about 15,000 t between 1947 and 1961. With increased exploitation on the offshore banks, landings increased to a maximum of about 35,500 t in 1968. Since 1969, landings have varied between about 16,000 t and 33,000 t (Fig. 2) reaching their lowest level in 1993.

In recent years the fishery has occurred year round with highest catches during June and July (Table 1) and is prosecuted primarily by otter trawlers less than 65 ft, tonnage classes 2 and 3, and by long liners less than 45 ft, tonnage classes 1 and 2 (Table 2). The majority of the decrease in landings during 1993 has come from the Scotian Shelf, predominantly unit area 4Xo, while those of the German Bank/Bay of Fundy areas have not dropped as markedly (Table 3). Reported landings since 1990 are considered to be more accurate due to the introduction of mandatory weigh-outs. *Dragger fishermen from the Bay of Fundy area commented that the winter-spring fishery in 1994 showed signs of improvement over recent years.*

CATCH AND WEIGHT AT AGE

The catch numbers at age for 1993 were based on 91 samples and were aggregated by gear type and quarter as has been done in recent years (Table 4). The 1990 year-class, and to a lesser extent the 1989 year-class, with mean lengths of 52 and 55 cm respectively, were predominant in both otter trawl and longline catches (Table 5). *Fishermen from the TC 3 dragger fleet commented that the bulk of the cod caught were between 50 and 60 cm while acknowledging the lack of steakers typically caught on the back of Browns Bank in mid-February.* The proportions of 2 and 3 year olds, the 1991 and 1990 year-classes, were high in comparison with the long term mean (Fig. 3) while the proportion for most other ages, barring the weak 1988 year-class, were similar to the mean. The catch for all ages over 5, particularly for the 1987 year-class which has been important in recent years, were lower than was forecast from last year's assessment (Fig. 4), with the shortfall in catch being made up by 2 and 3 year old fish. The catch and weight at age for 1993 were appended to those for 1970-92 from Gavaris (1993) and are shown in Tables 6 and 7. There have been no marked changes in average weight at age in recent years.

Ageing results showed good agreement between readings (Appendix 1). Re-reads from the first quarter, however, were skewed to older ages. Further investigation of patterns in comparative aging results will be conducted in the future .

ABUNDANCE INDICES

Commercial Catch Rates

Catch rate information from the commercial fisheries were used to derive indices of abundance trends. Data for vessels from the ITQ dragger fishery with a history of at least 4 years of activity were analyzed using a multiplicative model (Gavaris 1980) to standardize for vessel, unit area and month effects. Total annual landings for the longline fishery (tonnage classes 2 and 3) were divided

by number of trips. Commercial catch rates for both fisheries peaked in 1989 and 1990, and have declined steadily since then (Fig. 5). *Fishermen commented that commercial catch rates did not reflect changes in abundance due to several other factors which impact fishery performance. Key factors identified for the dragger fishery were the change to square mesh and changes in fishing practices associated with the introduction of individual quotas, and, for the longline fishery, trip limits and interannual changes in cod feeding behaviour. Many dragger captains commented that they no longer targeted for cod and therefore their present catch rates were not comparable to past catch rates.* Neither catch rate series was used further in the analysis due to uncertainties regarding interpretation of the trends as a reflection of stock abundance.

Research Surveys

Annual stratified random surveys have been conducted during summer since 1970. The spatial distribution of cod during the 1993 survey was similar to past years, though no areas of high abundance (catch>50kg) were detected (Fig. 6). The 1993 survey results show a marked decline in abundance (Table 8), particularly at older ages, however the abundance in strata 490 to 495 has remained relatively stable over the entire time period. The fraction of the total abundance occurring in the Bay of Fundy approached 50% in 1993 while in recent years it has only accounted for about 1/4 to 1/3 of the total. Recent results for ages 3 and older have identified the 1985 and 1987 year-classes as relatively strong and the 1988 year-class as very weak. The 1989 year-class also looks below average, while indications for the 1990 year-class suggest that it is about average. The relationship between historical population estimates and survey results are poor for ages 1 and 2 so these are not used quantitatively in the assessment; however, the preliminary indications they provide are for below average recruitment following the 1990 year-class.

ESTIMATION OF STOCK PARAMETERS

The adaptive framework (Gavaris 1988) was used to calibrate the sequential population analysis with the research survey results using the following data :

$C_{a,y}$ = catch	a=1 to 12, y=1970 to 1993
$I_{a,y}$ = Canadian summer survey	a=3 to 10, y=1972 to 1993 excluding 1988

where a indexes age and y indexes year. The summer survey results were compared to average (mid-year) population abundance. Data from 1970 and 1971 were excluded from the analysis because of unusual patterns in the residuals while 1988 data were excluded because catchability at all ages appeared to be anomalously high. While exclusion of the 1970 and 1971 data only impacted estimates of precision, the 1988 data were influential and their exclusion affected population abundance estimates. The estimates obtained when excluding the 1988 data were considered more appropriate as was done in last year's assessment. The index for age 6 in 1978 was also excluded because it was anomalously low, and if included, would impact the estimate of the calibration constant (slope in Fig. 7). All other available data since 1972 were used except when the index was 0 (logarithm not

defined). Statistical error in the survey data was assumed to be independent and identically distributed after taking logarithms and the error in the catch at age was assumed negligible. Natural mortality, M, was assumed constant and equal to 0.2 and the fishing mortality rate, F, for age 12 was calculated as the average for ages 5-7 in the same year.

Following the recommendation by Gavaris (1993), a model formulation using ln population abundance at the end of the terminal year (beginning of year y = 1994) as parameters was employed. Define the model parameters

$\phi_{a,t+1}$ = ln population abundance at age

for a = 4 to 12, with ages 1 to 3 fixed at values corresponding to the long-term geometric mean recruitment, and

κ_a = calibration constants for Canadian summer survey

for a = 3 to 10

ADAPT was used to solve for the parameters by minimizing the objective function

$$Q(\phi,\kappa) = \sum_{a,y}(q_{a,y}(\phi,\kappa))^2 = \sum_{a,y}(\ln(I_{a,y}) - \ln(\kappa_a \bar{N}_{a,y}(\phi)))^2$$

To avoid confusion, the average population abundance, $\bar{N}_{a,y}(\phi)$ is abbreviated by $\bar{N}_{a,y}$. It is calculated as:

$$\bar{N}_{a,y} = N_{a,y}\,(1-\exp[-(F_{a,y}+M)]) / (F_{a,y}+M)$$

For year y = 1994, the population abundances are obtained directly from the parameter estimates,

$$N_{a,t+1} = \exp[\phi_{a,t+1}]$$

For all other years, y = 1970 to 1993, the population abundance was computed using the virtual population analysis algorithm which incorporates the exponential decay model

$$N_{a,y} = N_{a+1,y+1}\exp[F_{a,y}+M]$$

where the fishing mortality for ages 1 to 11 is obtained by solving the catch equation using a Newton-Raphson algorithm,

$$N_{a,y} = C_{a,y}(F_{a,y} + M) / F_{a,y}(1 - \exp[-(F_{a,y} + M)])$$

The fishing mortality rate for age 12 was assumed equal to the average for ages 5 to 7,

Analytical approximations of variance and bias for population abundance estimates and corresponding projected yield were derived following Gavaris (1993). The relative error and bias indicate that there is substantial uncertainty in the estimates of population abundance (Table 9) reflecting the magnitude of the residuals (Fig. 7). The correspondence between the survey indices, scaled by the calibration constants and converted to biomass, and the sequential population analysis shows some time trends which warrant future investigation (Fig. 8).

ASSESSMENT RESULTS

For each cohort, the terminal population abundance estimates from the integrated model were adjusted for bias and used to construct the history of stock status (Tables 10 - 13). This approach, in the absence of unbiased point estimators with well determined statistical properties, was considered more appropriate than using the biased point estimates.

The analysis indicates that the 1985 and 1987 year-classes were among the strongest since 1970 (Fig. 9) and the 1990 year-class is about average. Excluding these, recruitment during the 1980s was generally lower than recruitment in the 1970s. The beginning of year population biomass for ages 3 and older is showing a slight increase after declining rapidly from a peak in 1990 to the lowest level in the time series (Fig. 10). It is noteworthy that the peak during the early 1980s was sustained for a longer period corresponding to the generally better recruitment, while the peak in 1990 which was due almost entirely to the 1985 and 1987 year-classes was of short duration. Although the commercial catch rates were not used for calibration, the trends they showed were consistent with the assessment results.

The total fishing mortality rate for ages 4 and older (Fig. 11), which generally fluctuated about 0.5, has increased rapidly since 1989 to about 1.0 in 1992 and declined somewhat in 1993. This exceeds twice $F_{0.1}$ and has likely resulted in lost yield due to capture of fish before their full growth potential has been realized. This also indicates that catch rates have been substantially lower than those which could be achieved at $F_{0.1}$.

PROGNOSIS

Yield projections indicated that the point estimates for projected yield were biased upward by about 10% and had a standard error of about 25% of the mean. As with population abundance estimates, the simple adjustment for bias was considered more appropriate than using the biased point estimate. Due to a lack of good abundance indices at younger ages, the incoming year-classes were assumed to be about equal to the long term geometric mean (Table 14).

If the TAC of 13,000 t is taken in 1994, the resulting fully recruited fishing mortality would be about 0.57 and the beginning of year 1996 biomass for ages 3 and older would increase to 58,000t. The yield for 1995 at $F_{0.1}$ would be about 6,300t (Fig. 12).

Population abundance estimates for a given age from successive assessments, are generally lower than the previous estimates (Fig. 13). This phenomenon has been observed for several stocks and is referred to as a retrospective pattern. Excluding the anomalous results from 1990, where population estimates were generally lower than those for following years, population estimates generally decrease by about 25% for ages 3 and older (Fig. 14). Adjusting population abundance estimates to account for the retrospective pattern indicates that a catch of 4,400t in 1995, rather than 6,300t, would more closely approximate the $F_{0.1}$ catch.

Beginning of year biomass for ages 3 and older has fluctuated between about 50,000t and 80,000t since 1970 and is currently at about its lowest level. Recent fishing mortality rates, and those implied by the current management plan, imply a loss in yield due to growth overfishing and significantly lower catch rates than would be realized at $F_{0.1}$. With no indication of good recruitment following the 1990 year-class, a lower fishing mortality rate would distribute the available yield over more years.

The proportion of landings comprised by small cod differed by gear sector (Fig. **15**). Long line catch was particularly weighted towards small cod. Recent studies indicate that size selection for cod by long line is dependent particularly on bait size, and secondarily on hook size (Halliday and Kenchington, 1993) . Differences in landings among gear sectors, however, may partially result from different geographic distributions among fleets. This will be explored further in future.

ACKNOWLEDGEMENTS

We appreciated the diligent sampling effort by D. Lyon and G. Donaldson and the insight of this fishery which they provided. We thank those members of the industry who took the time to discuss their experiences in the fishery with us.

LITERATURE CITED

Gavaris, S. 1980. Use of a multiplicative model to estimate catch rate and effort from commercial data. Can. J. Fish. Aquat. Sci. 37: 2272-2275.

Gavaris, S. 1988. An adaptive framework for the estimation of population size. CAFSAC Res. Doc. 88/29: 12p.

Gavaris, S. 1993. Assessment of the southwest Scotian Shelf and Bay of Fundy cod. DFO Res. Doc. 93/32: 25p.

Gavaris, S. 1993. Analytical estimates of reliability for the projected yield from commercial fisheries. p. 185-191. In S.J. Smith, J.J. Hunt and D. Rivard [ed.] Risk evaluation and biological reference points for fisheries management. Can. Spec. Publ. Fish. Aquat. Sci. 120.

Halliday, R. and T. Kenchington. 1993. Size selection of groundfish longline gear. Industry Services and Native Fisheries Project Summary 40: 4p.

Table 1. Nominal catch (t) of cod in Div. 4X (including Canadian catch in Div. 5Y) by month.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1984	1741	2013	735	788	1773	3453	3659	4522	2734	1656	1203	973	25251
1985	773	1695	941	1264	1982	2595	3200	2612	2720	1810	795	1065	21452
1986	902	1618	1756	1441	1421	1939	2737	1992	2574	1714	771	1107	19971
1987	1209	1825	1236	1050	1866	2771	2661	1821	1673	1394	882	571	18959
1988	2123	1345	521	963	1522	2929	3008	1942	2208	1290	618	992	19461
1989	2148	2346	1360	1705	1292	3535	1830	1772	1535	1278	637	411	19849
1990	2541	2064	712	700	1516	3080	3753	3089	2574	1698	1133	826	23686
1991	2013	2641	993	1663	2312	3113	3945	2880	2967	2208	1650	1241	27626
1992	2075	1746	1297	1497	1677	3565	3324	2752	2595	2318	1460	1474	25780
1993	657	903	993	995	1611	2309	2824	2217	1794	1029	562	73	15968

Table 2. Nominal catch of cod in Div. 4X (including Canadian catch in Div. 5Y) by gear type and tonnage class.

	OTB						GN		LL				
Year	0 & 1	2	3	4	5	>6	0 & 1	2 & 3	0 & 1	2	>3	Misc.	Total
1984	964	4198	5832	109	1513	-	1248	220	6870	2864	980	451	25249
1985	523	3954	5548	57	1185	-	1837	161	5348	1764	635	440	21452
1986	573	3662	5094	186	974	-	1453	196	4926	1961	576	369	19970
1987	312	2645	3489	516	929	-	1968	241	5663	2257	499	439	18958
1988	451	3784	3345	154	382	41	808	424	6026	3145	656	245	19461
1989	409	3933	4184	56	679	12	1267	461	5665	2341	635	205	19847
1990	505	3659	3566	104	113	44	1933	669	8826	3225	849	193	23686
1991	355	4598	5791	253	632	60	2225	615	8264	3852	853	129	27627
1992	236	4493	5709	128	717	3	1815	550	7672	3670	670	117	25780
1993	176	2778	3598	68	238	2	1368	525	5067	1792	310	45	15967

Table 3. Nominal catch (t) of cod in Div. 4X (including Canadian catch in Div. 5Y) by unit area.

Year	4Xm	Xn	Xo	Xp	Xq	Xr	Xs	Xu	5Y	Total
1984	2256	2251	6192	1655	2244	2959	1413	3192	3088	25250
1985	3006	1199	5438	1026	1999	2301	1510	3529	1443	21451
1986	2914	1762	4670	544	1753	1802	1500	4226	801	19972
1987	2675	1609	4777	1130	1240	858	1207	4983	479	18958
1988	1464	1086	5226	1271	1082	746	1109	7475	-	19459
1989	1370	1019	5506	2820	1360	1112	915	5193	555	19850
1990	1846	755	7915	1746	2238	1746	1722	5380	338	23686
1991	2552	1557	8963	2436	2763	4242	2559	2246	307	27625
1992	1509	1776	10296	1437	2770	3295	1489	2937	272	25781
1993	1339	1639	4842	1418	1949	2419	1396	775	191	15967

Table 4. Length-weight parameters and samples used for the computation of the 1993 catch and weight at age.

Gear	Period	a	b	No. of samples	Number measured	Number aged	Catch (t)
OTB	Q1	.0000081	3.0503	9	1951	387	1586
	Q2	.0000084	3.0410	18	3857	618	2671
	Q3	.0000087	3.0233	11	2669	397	2337
	Q4	.0000063	3.1152	3	602	63	268
LL, LHP	Q1	.0000081	3.0503	8	2338	328	950
	Q2	.0000084	3.0410	6	1470	248	1612
	Q3	.0000087	3.0233	17	2490	352	3482
	Q4	.0000063	3.1152	6	1540	192	1126
GN	Q1	.0000081	3.0503	-	-	-	15
	Q2	.0000084	3.0410	2	552	116	601
	Q3	.0000087	3.0233	6	709	79	1009
	Q4	.0000063	3.1152	5	890	70	268
Misc.	Q1	.0000081	3.0503	-	-	-	2
	Q2	.0000084	3.0410	-	-	-	31
	Q3	.0000087	3.0233	-	-	-	7
	Q4	.0000063	3.1152	-	-	-	2

Table 5. Landed numbers of cod at age (000s) in Div. 4X (including Canadian catch in Div. 5Y) for 1993 by gear type.

Age	1	2	3	4	5	6	7	8	9	10	11+
OT	-	129	1467	610	271	294	91	43	4	5	1
LL	-	732	1617	1521	392	296	64	22	1	6	1
GN	-	-	72	85	83	135	65	36	6	1	1

Table 6. Catch at age for cod in Division 4X (including Canadian catch in Division 5Y).

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
1	0	0	0	0	0	0	0	2	0	0
2	272	553	358	331	101	766	410	1609	285	326
3	1341	1302	2446	1857	2193	1556	1693	3063	1803	1294
4	1398	1031	3071	2432	2088	2955	2476	1683	2274	3405
5	1565	1324	1903	1952	1814	1022	1401	1606	1991	2632
6	980	1062	953	676	1171	679	467	775	2188	1217
7	415	452	165	295	267	365	190	272	636	703
8	78	388	122	75	209	88	122	257	199	218
9	215	165	141	159	116	58	74	101	55	99
10	52	159	67	68	109	35	18	81	49	79
11	17	32	4	52	98	26	7	36	9	23
12	26	72	2	15	39	14	2	39	16	13
1+	6378	6538	9232	7910	8205	7562	6860	9524	9505	10010
2+	6378	6538	9232	7910	8205	7562	6860	9522	9505	10010
3+	6106	5986	8874	7580	8103	6797	6450	7913	9220	9684

Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989
1	0	0	0	4	39	0	0	0	0	10
2	885	886	982	766	804	888	147	1055	439	519
3	4773	4063	2549	3896	2381	1594	3129	784	2996	2305
4	1952	4424	4476	2112	3243	1488	2204	2140	1665	3763
5	2476	1684	3332	2376	1845	2458	906	1016	1534	709
6	1288	1017	873	1148	923	1159	985	472	686	615
7	426	535	398	620	444	491	343	478	211	158
8	242	299	301	251	159	174	164	230	207	83
9	86	165	140	136	54	66	82	111	96	54
10	51	65	99	71	50	44	37	56	59	17
11	12	27	52	52	31	26	15	31	35	7
12	16	18	27	9	22	8	15	8	9	6
1+	12208	13183	13229	11440	9994	8396	8028	6383	7938	8247
2+	12208	13183	13229	11436	9955	8396	8027	6383	7938	8236
3+	11322	12297	12246	10671	9151	7508	7881	5328	7499	7717

Age	1990	1991	1992	1993
1	0	6	0	0
2	101	480	705	863
3	2195	1679	3380	3165
4	2463	4968	1947	2222
5	2633	1878	3317	748
6	586	1417	947	727
7	370	222	515	220
8	76	168	71	101
9	43	30	48	12
10	35	16	13	12
11	12	39	8	2
12	12	15	2	0
1+	8525	10917	10953	8072
2+	8525	10911	10953	8072
3+	8424	10430	10248	7209

Table 7. Average weight at age for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	0.51	0.51	0.51	0.51	0.51	0.51	0.51	0.48	0.51
2	0.65	0.61	0.69	0.73	0.60	0.69	0.60	1.04	0.84
3	1.37	0.87	1.40	1.26	1.09	1.23	1.19	1.26	1.57
4	2.00	1.70	2.02	2.19	1.55	2.14	2.15	1.86	1.91
5	3.00	2.73	2.45	3.10	2.62	3.15	3.00	2.34	2.39
6	4.85	3.87	4.14	3.62	4.38	6.13	4.42	4.28	3.54
7	6.07	6.19	4.96	4.90	5.53	6.63	6.07	5.76	4.17
8	6.84	7.05	6.83	7.63	6.56	8.97	8.56	7.75	6.16
9	5.14	9.11	6.14	9.54	8.62	9.41	10.84	9.08	6.18
10	8.04	10.18	6.36	11.28	8.90	13.52	12.01	9.44	9.22
11	12.84	13.44	16.55	10.42	11.27	13.30	16.17	10.75	6.56
12	17.38	12.77	15.01	10.55	15.41	13.54	12.47	15.41	7.23

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	0.51	0.51	0.51	0.51	0.36	0.38	0.37	0.38	0.51
2	0.83	0.71	0.75	0.82	0.85	0.95	0.83	0.80	0.92
3	1.27	1.41	1.25	1.33	1.33	1.50	1.41	1.29	1.46
4	2.04	2.17	1.99	1.85	1.85	2.00	1.97	1.90	2.16
5	3.11	2.98	2.80	2.84	2.61	2.73	2.52	2.63	3.17
6	4.15	4.75	3.60	4.13	4.21	3.82	3.53	3.96	3.89
7	5.34	6.71	5.64	5.46	5.59	5.42	4.96	5.02	5.55
8	7.26	6.93	7.25	7.08	8.05	7.61	6.89	7.48	7.89
9	8.65	9.57	8.38	8.38	10.27	9.34	8.09	9.51	9.13
10	11.24	9.81	11.21	9.07	11.43	11.69	9.87	9.20	11.90
11	10.65	11.86	12.29	10.63	11.59	13.27	12.41	11.90	12.95
12	12.00	14.11	12.42	14.16	15.10	14.15	14.52	14.38	15.53

Age	1988	1989	1990	1991	1992	1993
1	0.51	0.50	0.51	0.50	0.50	0.50
2	0.96	0.92	0.93	0.88	0.93	0.72
3	1.35	1.57	1.49	1.36	1.28	1.44
4	1.88	2.28	2.26	2.03	1.84	1.74
5	2.71	2.76	3.22	2.74	2.86	2.46
6	4.01	4.02	3.89	3.86	3.93	3.77
7	5.25	4.98	5.61	5.47	4.98	5.24
8	8.07	8.45	7.97	7.58	6.52	7.15
9	10.12	9.97	10.00	9.77	9.20	8.73
10	10.99	11.89	12.46	13.25	12.09	11.43
11	12.17	15.25	14.03	13.63	14.40	14.12
12	16.25	16.38	16.16	15.66	16.26	16.00

Table 8. Research survey mean number per tow for cod in Division 4X.

Age	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
3	1.62	0.57	2.29	0.82	1.43	2.16	0.88	0.89	1.43	1.16	0.90
4	1.28	1.13	0.54	1.50	1.18	1.32	1.26	1.01	0.58	1.30	0.94
5	0.36	0.36	0.82	1.27	1.04	0.40	0.68	0.91	0.53	0.68	0.78
6	0.25	0.14	0.48	0.50	0.42	0.65	0.00	0.51	0.72	0.44	0.44
7	0.11	0.08	0.06	0.40	0.21	0.18	0.19	0.23	0.23	0.24	0.12
8	0.27	0.03	0.00	0.08	0.12	0.11	0.05	0.16	0.11	0.20	0.13
9	0.20	0.09	0.02	0.05	0.03	0.02	0.04	0.03	0.06	0.05	0.11
10	0.08	0.02	0.01	0.00	0.03	0.01	0.00	0.03	0.00	0.05	0.03

Age	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
3	2.62	2.25	2.67	1.67	0.37	0.00	2.12	3.47	0.70	1.08	1.52
4	1.50	1.50	0.95	0.81	0.72	0.00	1.66	1.63	1.95	0.44	0.66
5	0.93	1.23	0.97	0.23	0.38	0.00	0.28	1.56	0.73	1.07	0.10
6	0.58	0.45	0.50	0.40	0.17	0.00	0.31	0.20	0.49	0.34	0.19
7	0.24	0.32	0.34	0.29	0.14	0.00	0.03	0.28	0.09	0.29	0.03
8	0.00	0.04	0.19	0.14	0.20	0.00	0.02	0.04	0.08	0.07	0.05
9	0.05	0.04	0.10	0.06	0.05	0.00	0.05	0.03	0.01	0.03	0.00
10	0.02	0.02	0.01	0.01	0.03	0.00	0.03	0.00	0.01	0.00	0.00

Table 9. Statistical properties of population abundance and survey calibration constants for cod in Division 4X.

Population abundance

Age	PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
4	8870	5435	0.61	1503	0.17
5	2586	1565	0.61	349	0.14
6	202	200	0.99	66	0.32
7	638	434	0.68	105	0.16
8	83	74	0.90	23	0.27
9	250	129	0.52	26	0.10
10	129	69	0.53	13	0.10
11	79	45	0.58	8	0.11
12	3	10	2.99	2	0.69

July survey calibration constants

Age	PAR. EST.	STD. ERR.	REL. ERR.	BIAS	REL. BIAS
3	0.1339	0.0157	0.1170	0.0004	0.0031
4	0.1709	0.0198	0.1157	0.0006	0.0035
5	0.2036	0.0237	0.1164	0.0008	0.0040
6	0.2578	0.0308	0.1194	0.0010	0.0038
7	0.2353	0.0278	0.1181	0.0010	0.0043
8	0.2450	0.0308	0.1257	0.0017	0.0070
9	0.2473	0.0299	0.1209	0.0021	0.0085
10	0.2309	0.0309	0.1340	0.0019	0.0084

Table 10. Estimated bias adjusted population numbers (000s) at the beginning of the year for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	19383	15249	20597	24389	20328	25486	24606	17239	32528
2	16654	15869	12485	16864	19968	16643	20866	20145	14112
3	9182	13389	12493	9898	13508	16257	12934	16713	15038
4	6603	6303	9785	8015	6423	9075	11902	9057	10911
5	4623	4142	4228	5233	4361	3370	4756	7504	5893
6	2581	2369	2193	1739	2518	1929	1834	2626	4691
7	1726	1227	978	933	813	1002	965	1079	1449
8	736	1020	596	652	497	424	491	618	638
9	533	532	484	378	466	217	267	292	274
10	109	242	287	268	165	277	125	152	147
11	247	43	54	174	158	37	196	87	51
12	79	186	6	41	96	41	7	154	38
13	0	41	88	3	20	43	21	4	90
1+	62456	60612	64272	68585	69321	74801	78970	75670	85860
2+	43073	45363	43675	44196	48993	49315	54364	58430	53332
3+	26419	29494	31190	27333	29025	32672	33498	38285	39220

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	29378	20989	26849	13153	13917	19305	10252	28123	17866
2	26632	24052	17184	21982	10769	11391	15771	8393	23025
3	11296	21510	18891	13268	17109	8124	8599	12109	6739
4	10680	8077	13291	11790	8556	10483	4497	5598	7083
5	6876	5663	4847	6879	5603	5094	5648	2336	2589
6	3023	3249	2397	2445	2617	2438	2502	2400	1093
7	1861	1374	1494	1042	1212	1104	1161	999	1074
8	611	887	740	740	493	431	502	506	507
9	342	303	507	335	333	176	209	254	266
10	175	191	169	266	148	150	95	112	133
11	76	71	109	80	128	57	77	38	58
12	34	41	47	65	18	58	19	40	18
13	17	16	19	22	29	7	27	8	19
1+	91000	86423	86547	72067	60932	58818	49359	60915	60469
2+	61622	65434	59698	58915	47016	39512	39107	32792	42603
3+	34990	41382	42514	36932	36247	28122	23336	24399	19578

Age	1988	1989	1990	1991	1992	1993	1994
1	26437	9047	15674	19601	19067	19542	20000
2	14628	21645	7397	12833	16043	15611	16000
3	17897	11579	17252	5965	10072	12497	12000
4	4808	11942	7394	12138	3365	5188	7368
5	3862	2430	6372	3825	5443	993	2237
6	1200	1774	1348	2835	1433	1455	136
7	467	361	896	573	1039	316	534
8	447	192	153	399	269	385	60
9	207	178	82	56	174	156	224
10	117	83	97	28	19	99	117
11	58	42	52	48	9	4	70
12	19	16	28	33	3	0	1
13	8	7	8	12	13	1	0
1+	70154	59295	56753	58346	56949	56247	58746
2+	43717	50248	41079	38745	37882	36704	38746
3+	29089	28603	33682	25912	21839	21094	22746

Table 11. Estimated bias adjusted population biomass (000 t) at the beginning of the year for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	9126	6730	8876	11598	9018	12099	8853	6240	13095
2	9610	8870	7444	10299	11050	9873	11567	14736	8982
3	8661	10044	11527	9252	12008	13919	11700	14548	19255
4	10946	9612	12958	14037	8974	13848	19317	13473	16978
5	11342	9689	8620	13108	10448	7445	12060	16827	12412
6	9848	8074	7369	5182	9283	7724	6851	9412	13520
7	9357	6716	4283	4198	3635	5402	5886	5448	6122
8	4740	6666	3871	4009	2815	2983	3697	4240	3798
9	3161	4201	3183	3049	3781	1707	2636	2572	1896
10	703	1747	2181	2234	1522	2992	1333	1535	1347
11	2505	445	705	1418	1782	399	2892	984	405
12	1187	2385	83	536	1217	506	85	2429	334
13	0	839	1118	45	168	807	309	47	1358
1+	81185	76018	72219	78964	75700	79705	87186	92492	99504
2+	72059	69288	63343	67366	66682	67605	78334	86251	86409
3+	62450	60418	55899	57067	55632	57732	66767	71515	77427

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	12819	8881	10928	5251	3079	4979	2583	6887	6686
2	17409	14506	10687	14214	7098	6672	8830	4561	13577
3	11704	23336	17756	13291	17813	9154	9957	12501	7279
4	19102	13414	22265	17896	13434	17114	7732	9143	11843
5	16782	13944	11951	16345	12317	11457	12682	5316	6347
6	9521	12486	7853	8317	9052	7704	7765	7573	3495
7	8097	7247	7735	4621	5819	5271	5053	4204	5035
8	3361	5397	5157	4676	3267	2810	3068	3080	3193
9	2498	2523	3864	2611	2842	1530	1640	2053	2197
10	1455	1756	1756	2316	1448	1641	914	964	1416
11	752	821	1202	876	1316	701	931	416	629
12	303	504	574	858	234	746	263	536	242
13	99	258	313	285	439	133	430	120	293
1+	103903	105073	102042	91559	78157	69911	61850	57353	62231
2+	91084	96192	91114	86308	75078	64933	59267	50466	55545
3+	73675	81686	80427	72094	67980	58261	50437	45905	41968

Age	1988	1989	1990	1991	1992	1993	1994
1	10144	3286	6143	7190	7961	8160	8013
2	10287	14846	5011	8617	10934	9347	10410
3	19876	14258	20173	6678	10688	14439	13344
4	7960	20912	13948	21107	5307	7748	11812
5	9356	5530	17250	9525	13114	2108	5236
6	4280	5855	4417	10000	4704	4782	458
7	2113	1614	4252	2643	4557	1436	2407
8	2990	1277	962	2599	1605	2297	369
9	1851	1597	750	493	1453	1176	1845
10	1170	912	1076	324	203	1015	1270
11	699	543	677	621	124	46	934
12	276	228	437	482	51	2	16
13	137	132	150	203	217	17	2
1+	71140	70989	75245	70484	60918	52574	56115
2+	60996	67703	69102	63294	52957	44414	48102
3+	50709	52857	64092	54676	42023	35067	37693

Table 12. Estimated population biomass (000 t) at mid-year for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978
1	9012	7090	9577	11340	9452	11850	11441	7499	15124
2	9711	8595	7721	10995	10775	10091	11209	18218	10678
3	10492	9964	14104	10133	12115	17151	12980	17212	20019
4	10576	8814	14713	13172	7328	14318	20452	13656	16727
5	10127	8370	6867	11513	7800	7961	10765	14035	10284
6	8823	6080	6096	4410	7209	8532	6298	8471	10848
7	8140	5404	3987	3388	3300	4749	4726	4833	4048
8	4300	5064	3267	4225	2217	3045	3275	3279	2924
9	1893	3615	2246	2452	3133	1573	2213	1919	1363
10	570	1276	1435	2350	760	3164	1259	876	992
11	2761	249	779	1368	978	234	2812	634	277
12	1016	1671	63	306	1018	403	64	1838	187
1+	77420	66193	70854	75652	66082	83071	87494	92470	93470
2+	68408	59103	61277	64312	56631	71221	76054	84971	78346
3+	58697	50508	53556	53317	45856	61129	64845	66753	67668

Age	1979	1980	1981	1982	1983	1984	1985	1986	1987
1	13659	9759	12484	6115	4540	6642	3438	9686	8307
2	19975	15150	11417	15847	7948	9463	11434	6014	18623
3	12208	24123	18768	14295	17990	9193	9837	12109	8362
4	16093	13714	19335	15378	12364	15667	6506	7397	11493
5	15055	11317	9842	12537	9938	9956	9549	4299	5727
6	8673	10724	5862	7252	7377	6579	5776	6525	2866
7	7022	6871	6057	4002	4218	4140	3910	3642	3971
8	3185	4708	3703	3610	2481	2335	2506	2789	2644
9	2242	2199	3129	1919	2356	1230	1257	1778	1655
10	1295	1435	1337	1713	1089	1281	617	752	1077
11	604	693	1048	447	1028	458	704	319	451
12	287	407	414	631	183	580	183	406	187
1+	100298	101099	93396	83746	71513	67522	55716	55714	65362
2+	86639	91340	80912	77630	66973	60881	52278	46028	57055
3+	66663	76190	69496	61783	59025	51418	40844	40015	38433

Age	1988	1989	1990	1991	1992	1993
1	12292	4064	7288	8881	8641	8856
2	12574	17758	6156	10018	13188	9842
3	19841	14677	21688	6153	9431	13950
4	6534	20174	12249	16930	3568	6107
5	7279	5071	14068	6678	8652	1059
6	2804	5163	3523	6911	2906	3467
7	1624	1205	3443	2198	3280	808
8	2357	1089	768	2055	1351	2125
9	1374	1328	502	332	1224	1182
10	803	792	863	223	110	958
11	398	524	585	228	30	29
12	198	189	306	335	31	2
1+	68080	72035	71439	60942	52411	48384
2+	55788	67970	64151	52061	43771	39528
3+	43214	50212	57995	42043	30583	29687

Table 13. Estimated bias adjusted fishing mortality for cod in Division 4X.

Age	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.02	0.04	0.03	0.02	0.01	0.05	0.02	0.09	0.02	0.01	0.04	0.06
3	0.18	0.11	0.24	0.23	0.20	0.11	0.16	0.23	0.14	0.14	0.28	0.27
4	0.27	0.20	0.43	0.41	0.45	0.45	0.26	0.23	0.26	0.43	0.31	0.46
5	0.47	0.44	0.69	0.53	0.62	0.41	0.39	0.27	0.47	0.55	0.66	0.48
6	0.54	0.68	0.65	0.56	0.72	0.49	0.33	0.39	0.72	0.59	0.58	0.63
7	0.33	0.52	0.21	0.43	0.45	0.51	0.25	0.33	0.66	0.54	0.42	0.50
8	0.12	0.55	0.26	0.14	0.63	0.26	0.32	0.61	0.42	0.50	0.36	0.59
9	0.59	0.42	0.39	0.63	0.32	0.35	0.37	0.48	0.25	0.39	0.38	0.45
10	0.74	1.29	0.30	0.33	1.30	0.15	0.17	0.88	0.46	0.70	0.35	0.55
11	0.08	1.79	0.09	0.40	1.15	1.51	0.04	0.63	0.21	0.41	0.21	0.32
12	0.45	0.55	0.52	0.51	0.60	0.48	0.33	0.33	0.62	0.56	0.56	0.54

Age	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.05	0.08	0.08	0.06	0.02	0.05	0.03	0.03	0.02	0.04	0.05	0.06
3	0.24	0.29	0.39	0.23	0.34	0.14	0.20	0.25	0.15	0.37	0.46	0.33
4	0.54	0.32	0.42	0.46	0.57	0.41	0.48	0.43	0.46	0.60	1.02	0.64
5	0.77	0.63	0.51	0.66	0.56	0.57	0.58	0.39	0.61	0.78	1.12	1.79
6	0.50	0.66	0.54	0.72	0.60	0.65	1.00	0.48	0.65	0.80	1.31	0.80
7	0.55	0.83	0.59	0.63	0.48	0.68	0.69	0.66	0.61	0.56	0.79	1.46
8	0.60	0.83	0.52	0.48	0.44	0.70	0.72	0.65	0.81	0.63	0.35	0.34
9	0.62	0.60	0.42	0.43	0.45	0.62	0.71	0.41	0.86	0.90	0.36	0.09
10	0.53	0.76	0.46	0.71	0.46	0.63	0.82	0.26	0.51	0.94	1.47	0.14
11	1.27	0.59	0.90	0.46	0.57	0.91	1.08	0.21	0.28	2.44	4.10	0.98
12	0.61	0.72	0.55	0.67	0.55	0.64	0.76	0.51	0.62	0.71	1.05	0.00

Table 14. Projections for cod in Division 4X.

Weight (Mid-Year)

	1994	1995
1	0.50	0.50
2	0.84	0.84
3	1.36	1.36
4	1.87	1.87
5	2.69	2.69
6	3.86	3.86
7	5.23	5.23
8	7.09	7.09
9	9.23	9.23
10	12.26	12.26
11	14.05	14.05
12	15.98	15.98

Weight (Beginning Year)

	1994	1995	1996
1	0.41	0.41	0.41
2	0.64	0.64	0.64
3	1.11	1.11	1.11
4	1.56	1.56	1.56
5	2.29	2.29	2.29
6	3.31	3.31	3.31
7	4.48	4.48	4.48
8	6.03	6.03	6.03
9	8.05	8.05	8.05
10	10.67	10.67	10.67
11	13.39	13.39	13.39
12	15.01	15.01	15.01
13	17.10	17.10	17.10

Beginning of Year

Population Numbers

Age	1994	1995	1996
1	20000	20000	20000
2	16000	16375	16375
3	12000	12734	13273
4	7368	8057	9721
5	2237	3943	5677
6	136	1039	2643
7	534	63	696
8	60	248	42
9	224	28	166
10	117	104	19
11	70	54	70
12	1	33	36
13	0	1	22
1+	58746	62677	68740
2+	38746	42677	48740
3+	22746	26302	32366
4+	10746	13569	19093

Population Biomass

Age	1994	1995	1996
1	8238	8238	8238
2	10298	10539	10539
3	13314	14128	14727
4	11479	12552	15144
5	5125	9033	13007
6	451	3441	8753
7	2390	283	3119
8	361	1494	256
9	1801	224	1337
10	1245	1109	199
11	940	726	933
12	16	490	546
13	2	9	374
1+	55661	62266	77171
2+	47423	54028	68933
3+	37125	43489	58394
4+	23810	29361	43667

Table 14. continued

Mid-Year

Population Numbers

Age	1994	1995
1	18127	18127
2	14305	14770
3	9898	11159
4	5478	6798
5	1562	3250
6	95	856
7	373	52
8	42	204
9	156	23
10	82	86
11	49	45
12	1	27
1+	50167	55396
2+	32040	37269
3+	17735	22500
4+	7837	11341

Population Biomass

Age	1994	1995
1	9063	9063
2	12040	12431
3	13438	15151
4	10235	12701
5	4196	8729
6	367	3302
7	1948	273
8	297	1447
9	1443	212
10	999	1050
11	689	628
12	12	429
1+	54727	65416
2+	45663	56352
3+	33624	43921
4+	20186	28771

Fishing Mortality

Age	1994	1995
1	0.00	0.00
2	0.03	0.01
3	0.20	0.07
4	0.43	0.15
5	0.57	0.20
6	0.57	0.20
7	0.57	0.20
8	0.57	0.20
9	0.57	0.20
10	0.57	0.20
11	0.57	0.20
12	0.57	0.20

Catch Numbers

Age	1994	1995
1	0	0
2	405	148
3	1964	781
4	2329	1020
5	886	650
6	54	171
7	211	10
8	24	41
9	89	5
10	46	17
11	28	9
12	0	5
1+	6036	2857
2+	6036	2857
3+	5630	2709
4+	3667	1928

Catch Biomass

Age	1994	1995
1	0	0
2	341	124
3	2666	1061
4	4352	1905
5	2379	1746
6	208	660
7	1104	55
8	168	289
9	818	42
10	566	210
11	390	126
12	7	86
1+	13000	6304
2+	13000	6304
3+	12659	6180
4+	9993	5119

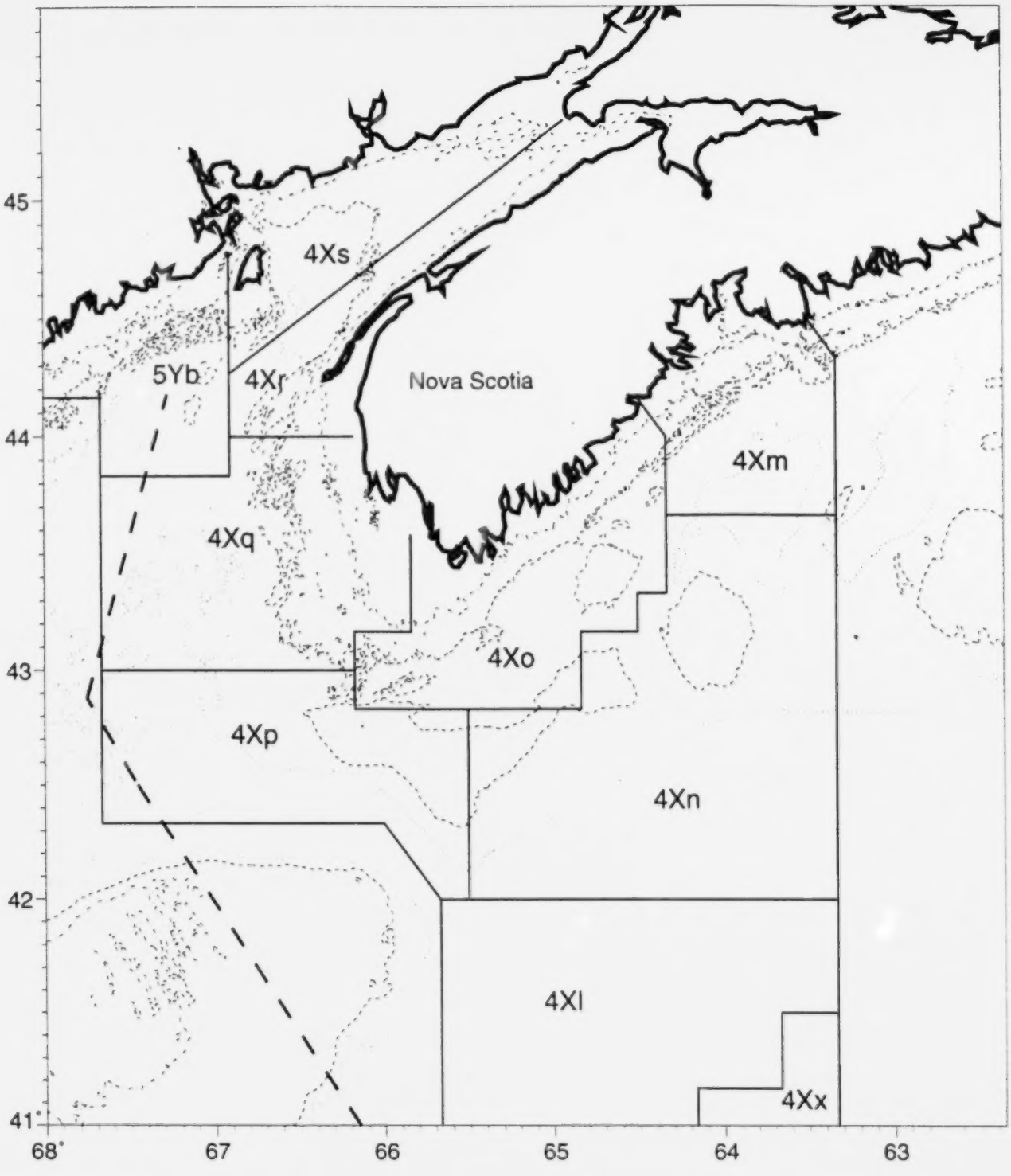


Fig. 1. Canadian fisheries statistical unit areas in NAFO Division 4X.

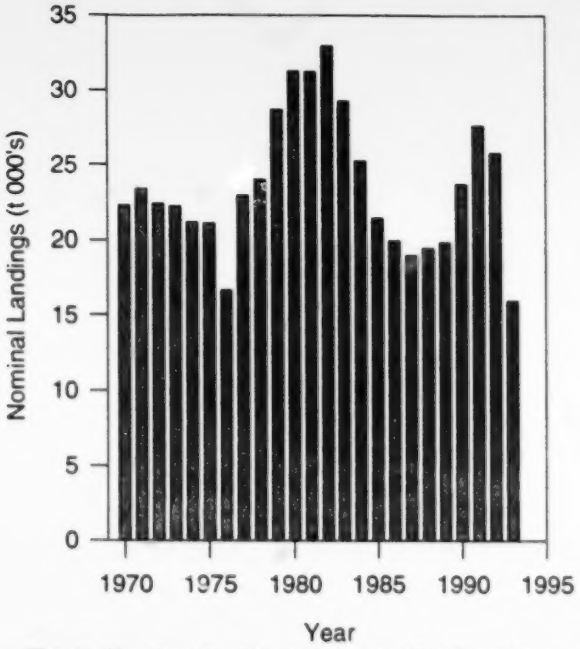


Fig. 2. Nominal landings of cod in Division 4X including catches by Canada in Division 5Y.

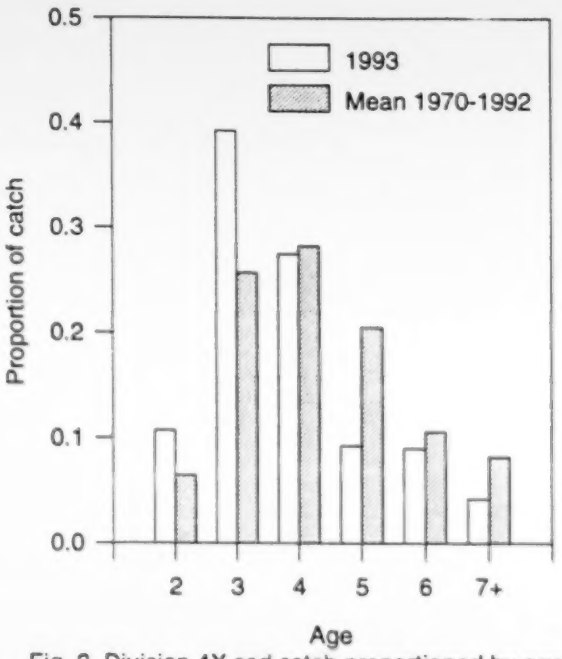


Fig. 3. Division 4X cod catch proportioned by age for 1993 compared to mean for 1970-92.

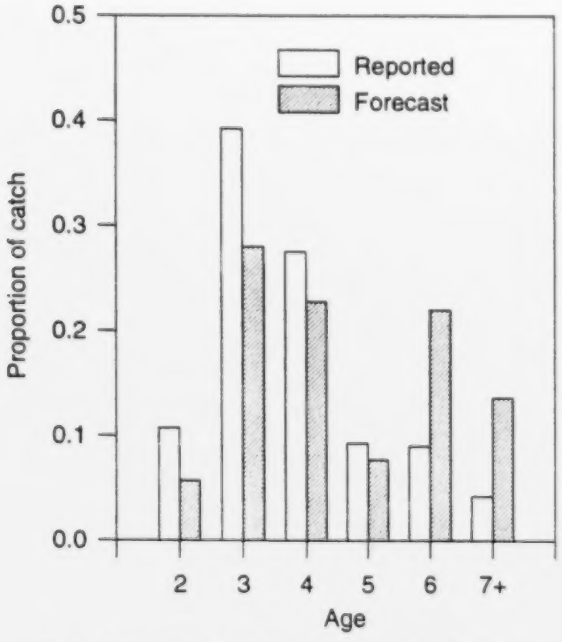


Fig.4. Reported and forecast catch in Division 4X for 1993 proportioned by age.

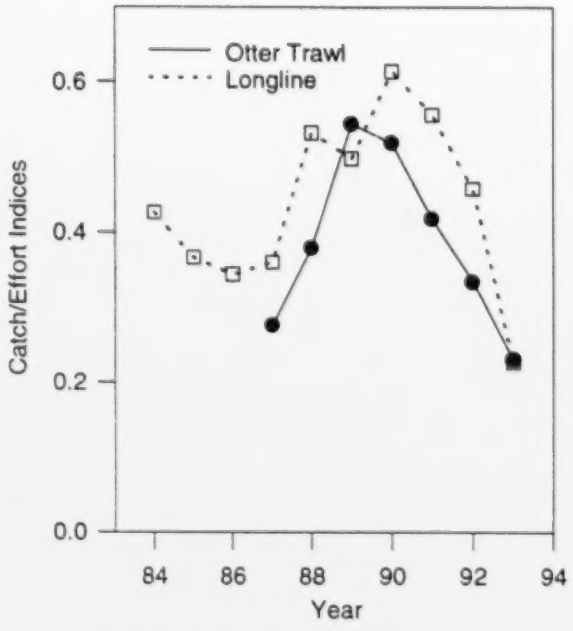


Fig. 5. Catch rate indicest for cod in Division 4X from the longline and otter trawl fisheries.

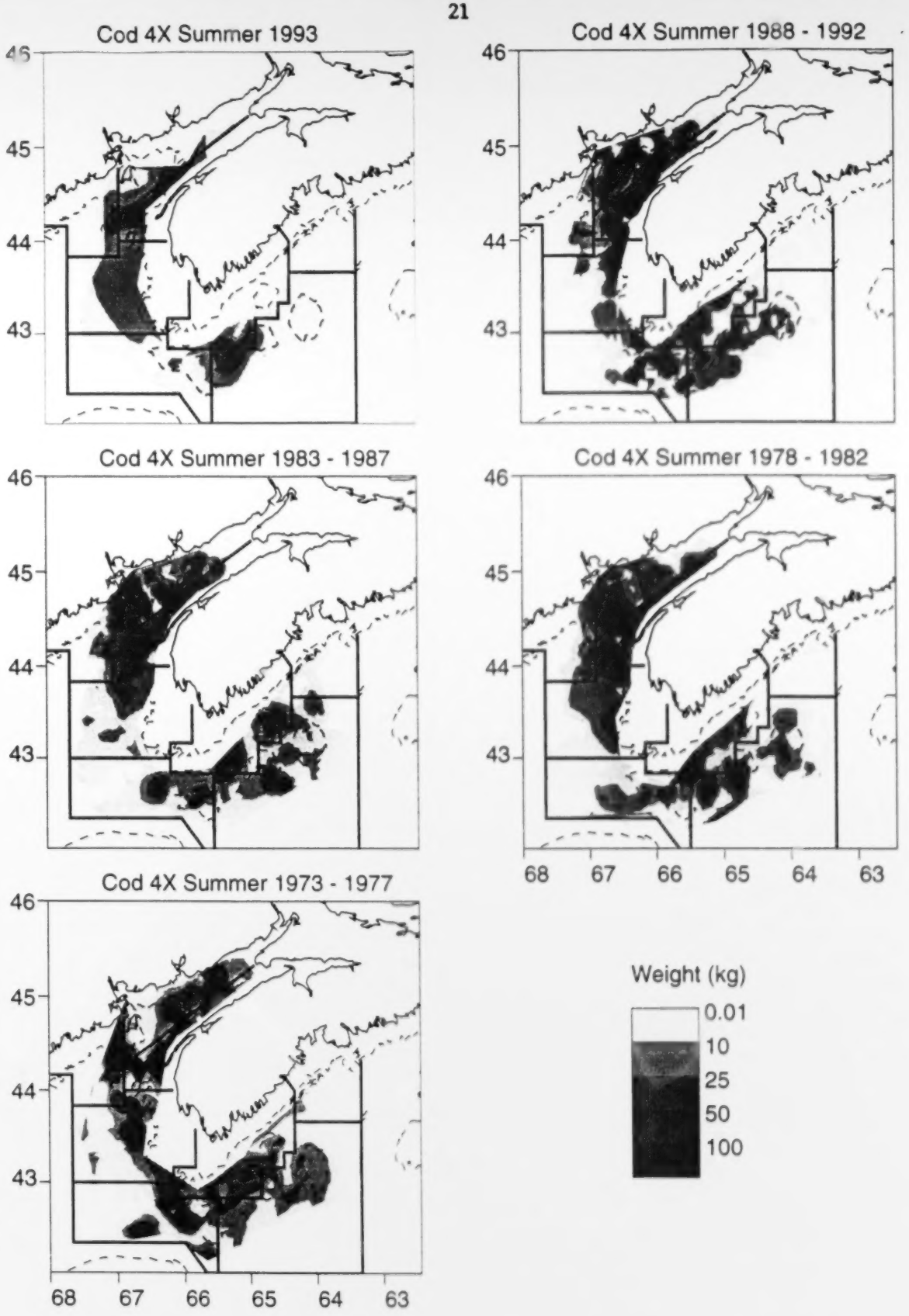


Fig. 6 Contoured abundance plots for 4X cod from summer groundfish survey catches.

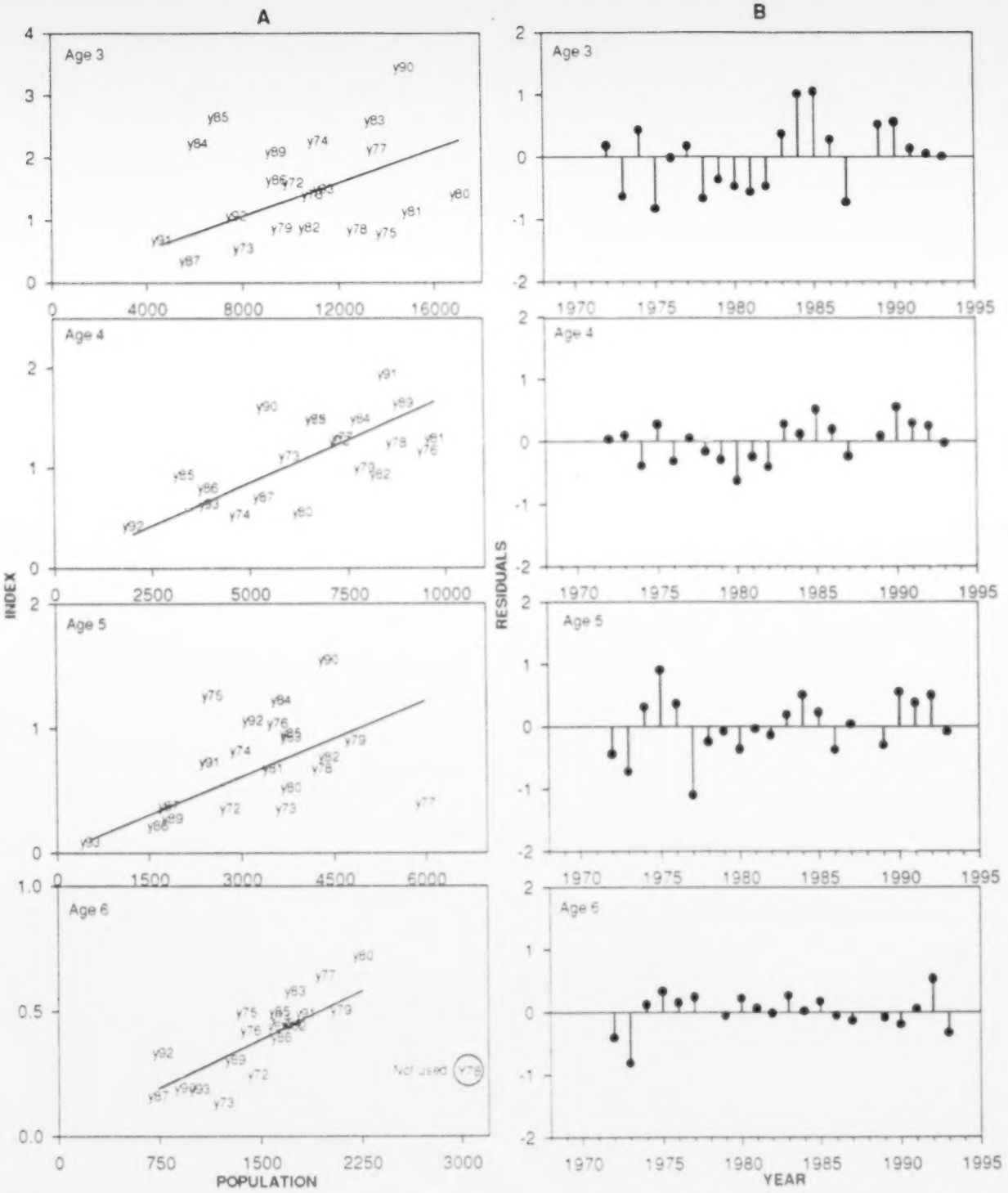


Fig. 7. Age by age plots of A) the observed and predicted abundance index versus population numbers and B) residuals plotted against year for the Canadian spring survey for cod in divisions 4X and 5Y.

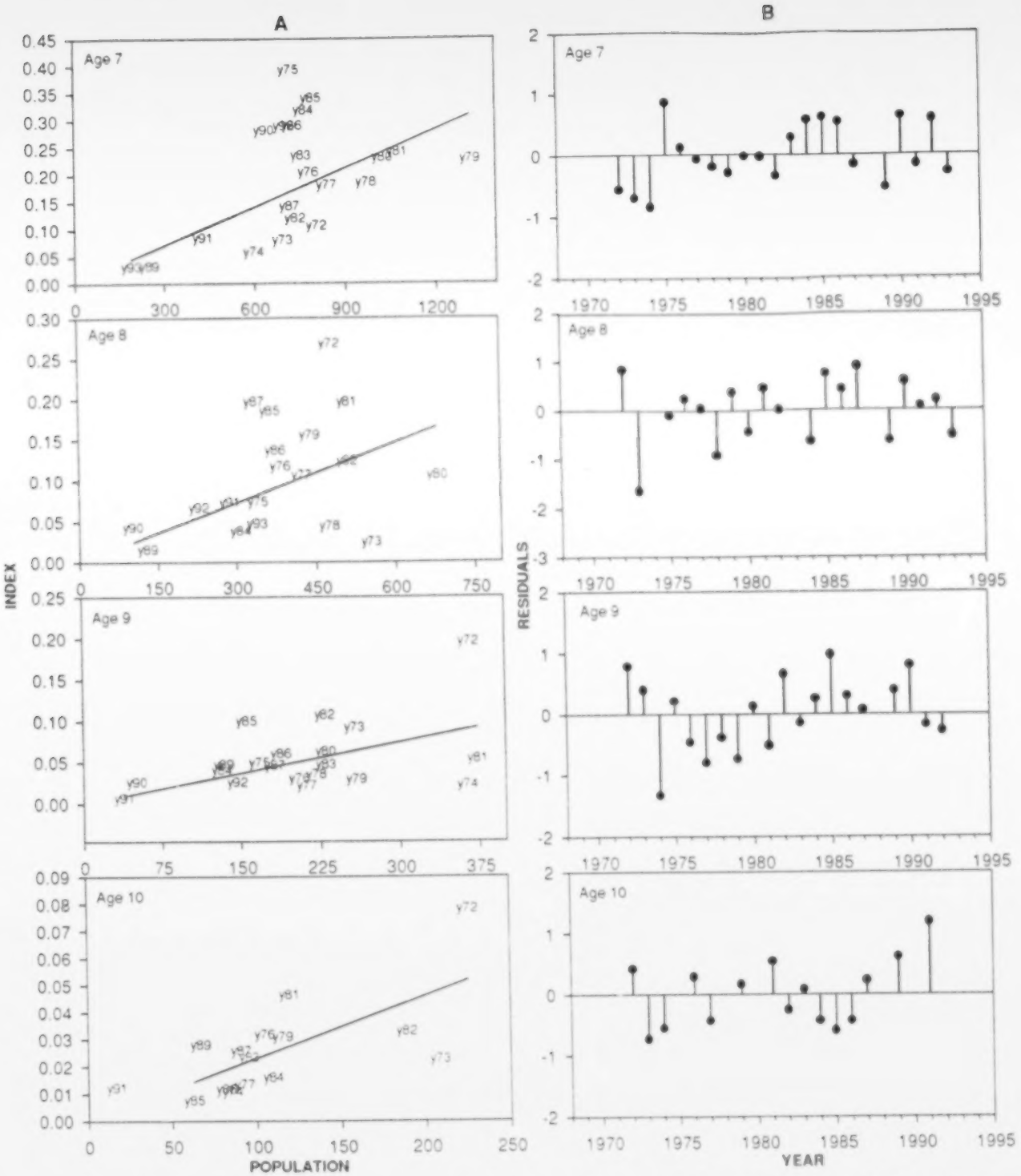
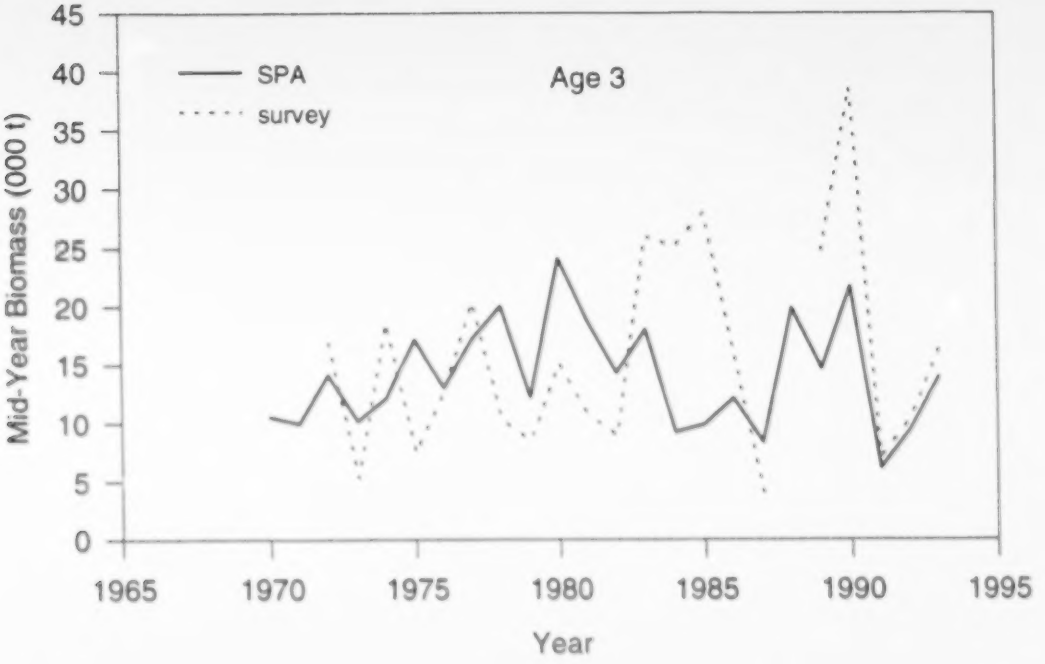


Fig. 7 (cont.). Age by age plots of A) the observed and predicted abundance index versus population numbers and B) residuals plotted against year for the Canadian spring survey for cod in Divisions 4X and 5Y.



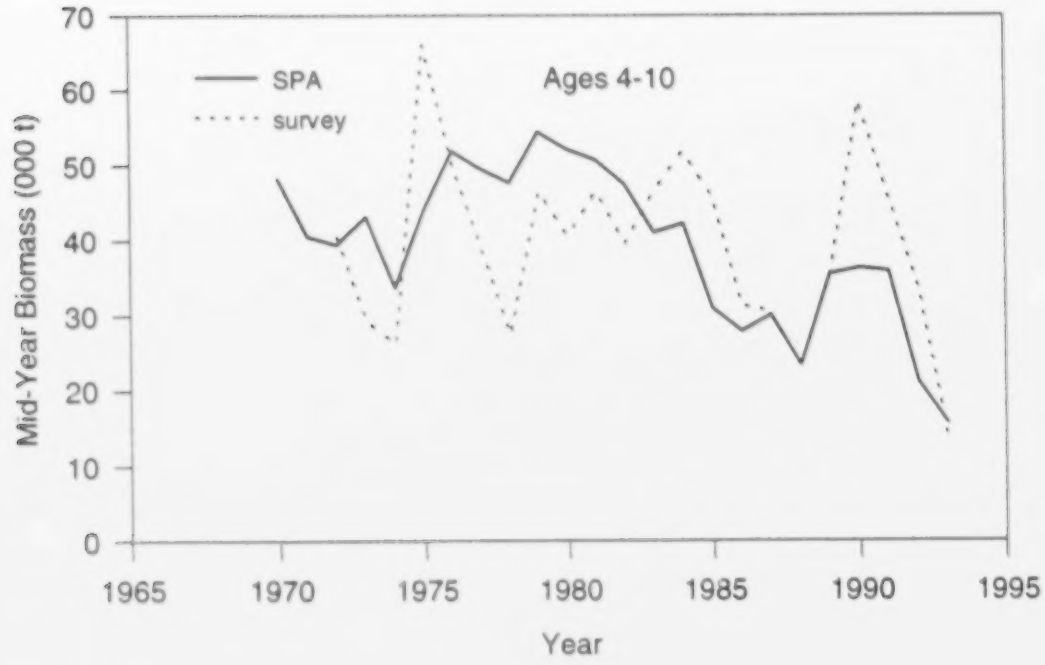


Fig. 8. Mid-year biomass from sequential population analysis (SPA) and research survey index (adjusted by calibration constants) for cod in Division 4X.

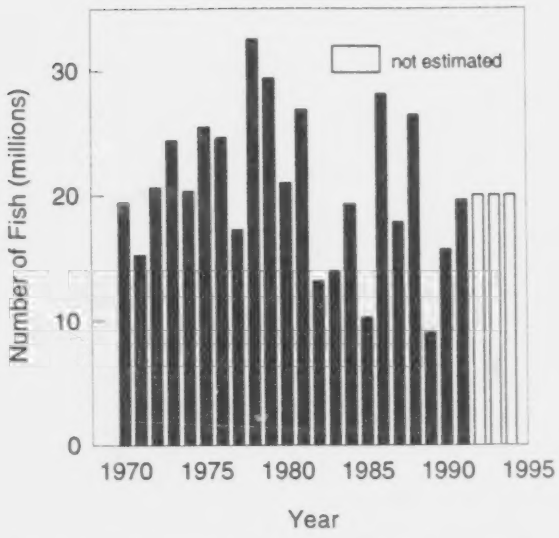


Fig. 9. Recruitment (age 1) for cod in Division 4X.

Fig.10. Beginning of year biomass (3+) for cod in Division 4X.

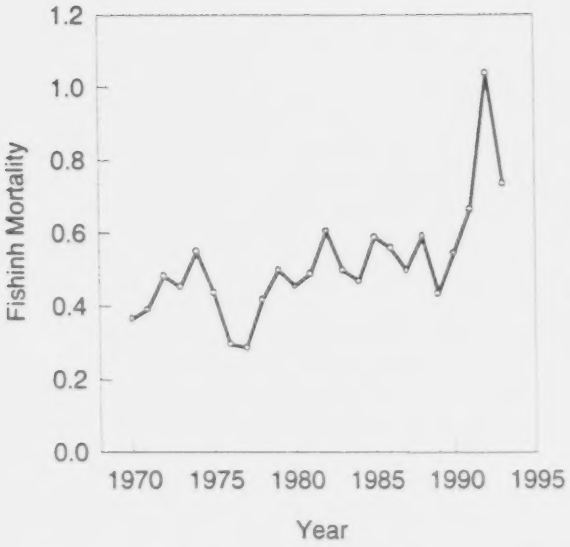


Fig. 11. Fishing mortality (4+) for cod in Division 4X.

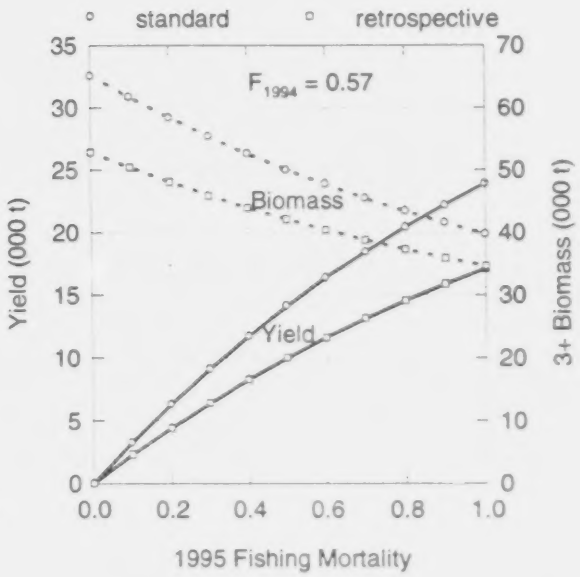


Fig. 12. Projected 4X cod yield for 1995 and beginning of year biomass in 1996.

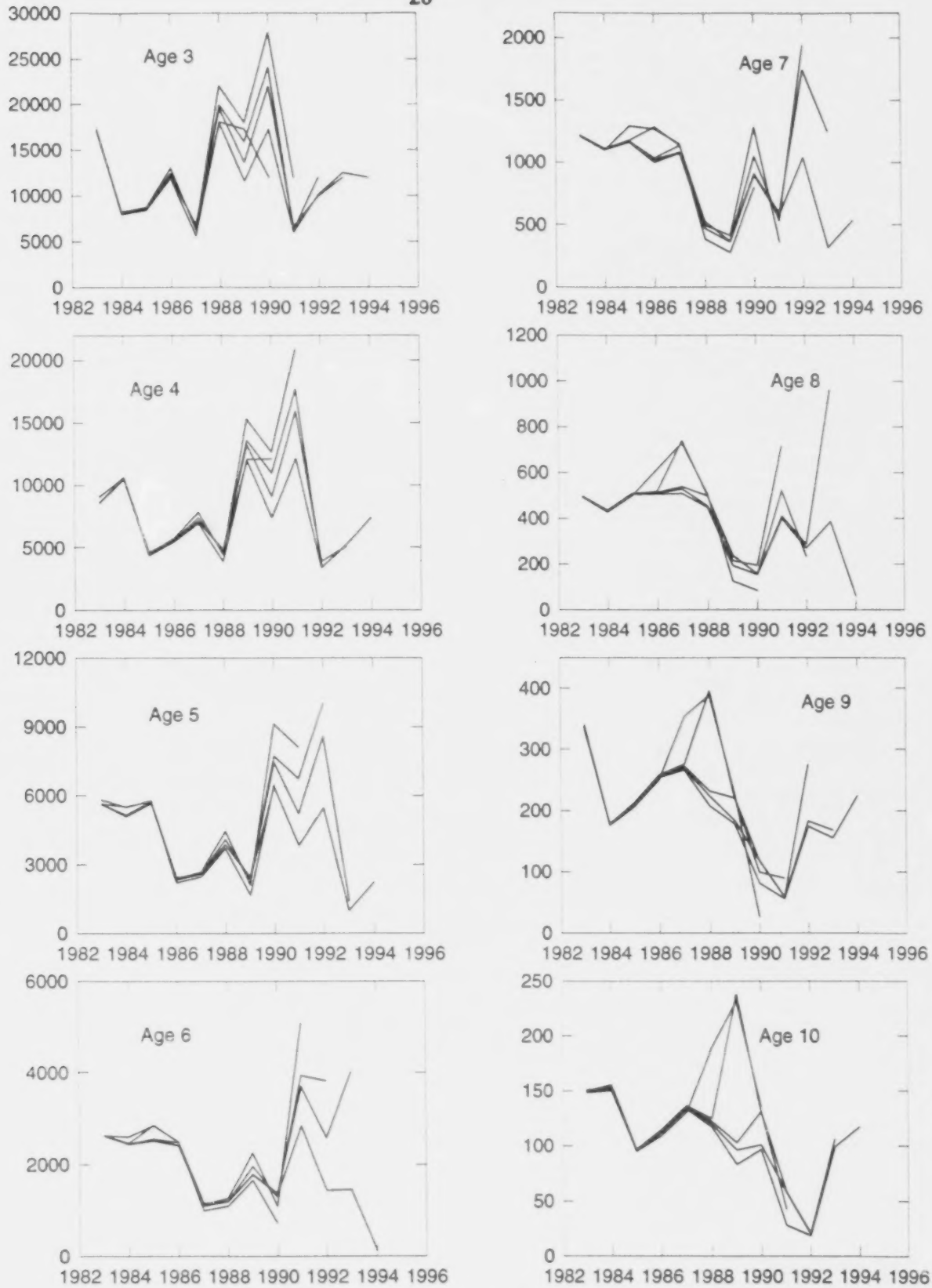


Fig. 13. Retrospective analysis of population abundance for cod in Division 4X.

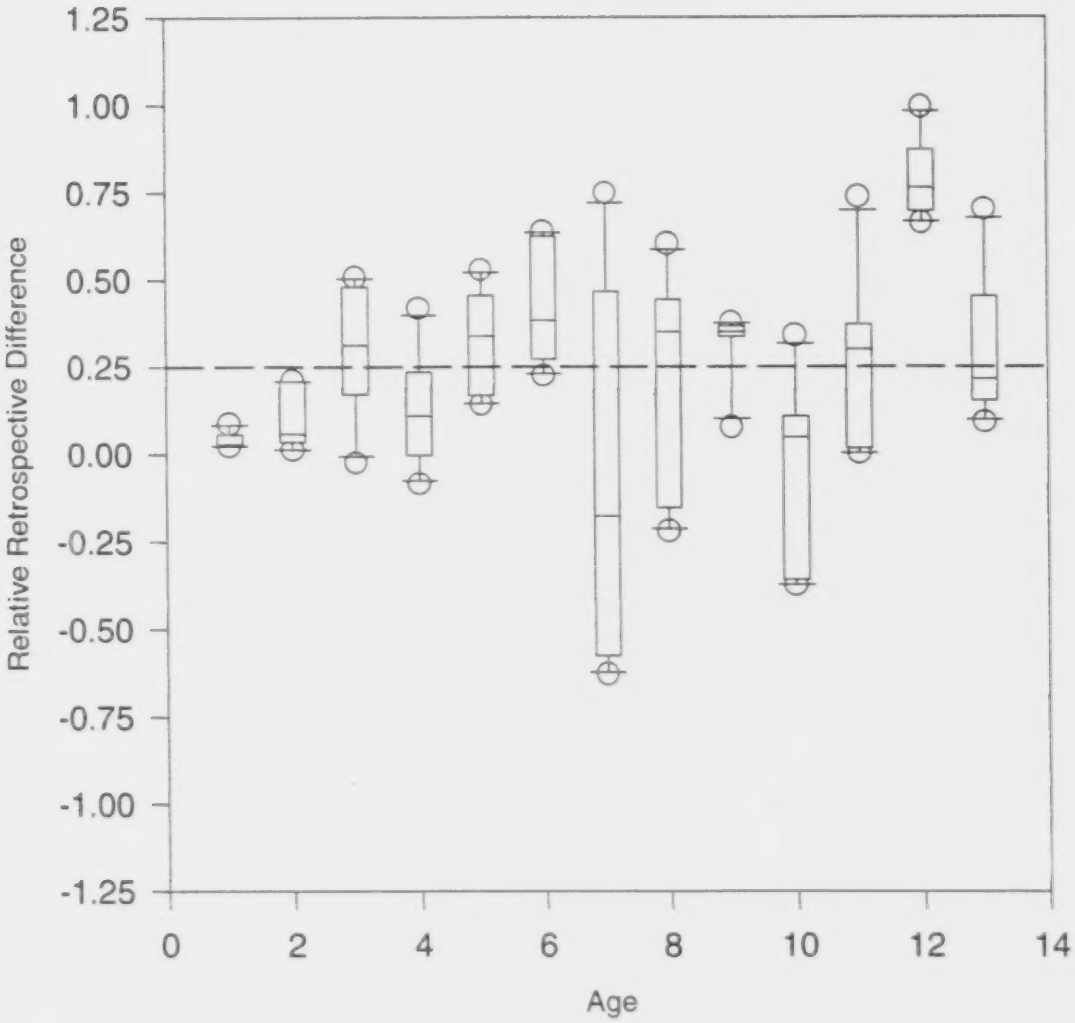


Fig. 14. Box and whisker plot of relative difference in estimates of abundance from successive assessments for years 1991 to 1994. A positive difference means that subsequent estimates were higher, the typical retrospective pattern.

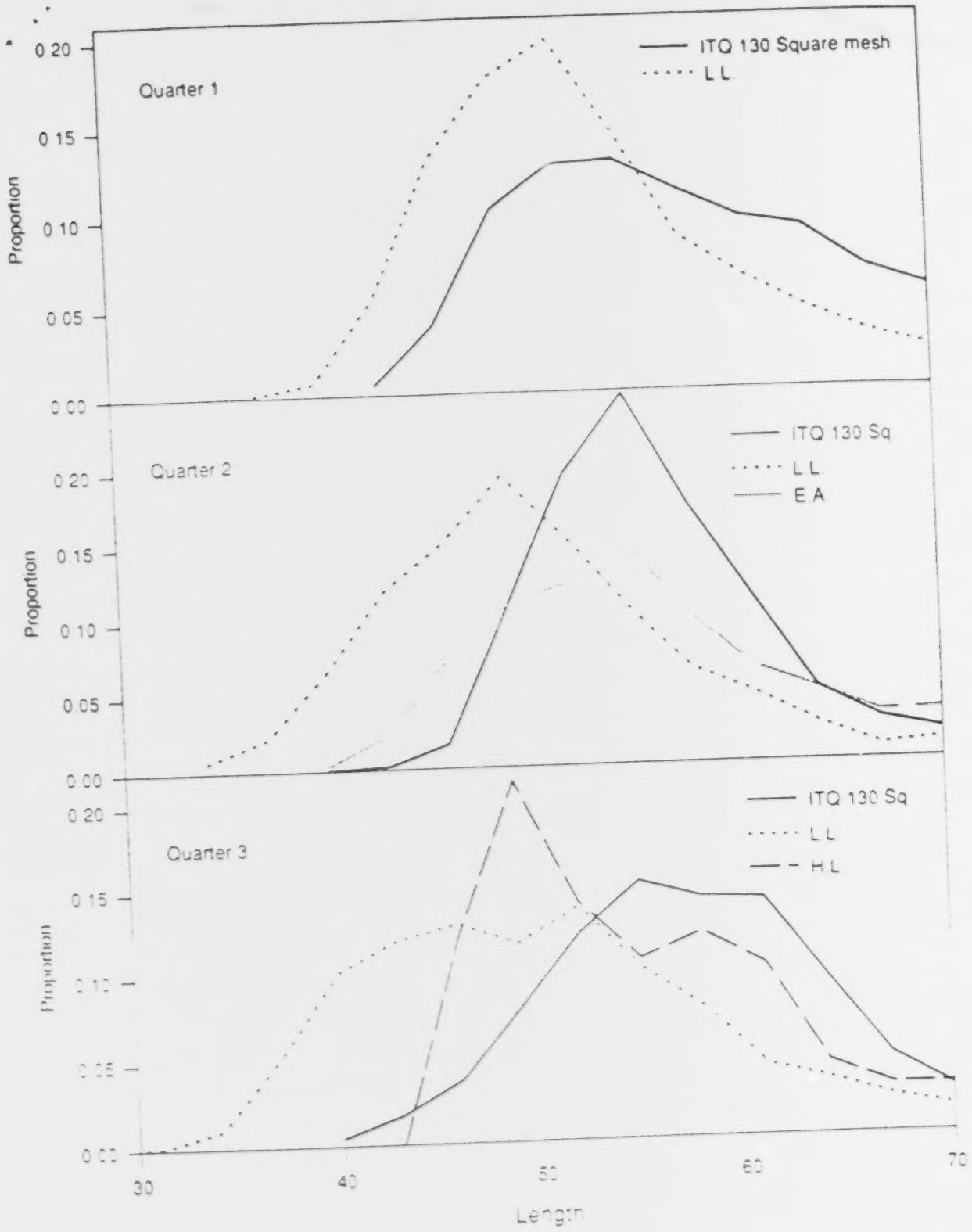


Fig. 15 Length frequencies of 4X cod from port samples for a variety of gear sectors.

Appendix 1.

Table A1. Comparison of ages from 2 independent readings by L. Brown of otoliths from the first quarter 4X cod commercial fishery.

Second reading \ First reading	1	2	3	4	5	6	7	8	9	10	Omit	Tot.
1												
2		3										3
3		2	12									14
4			7	20								27
5				3	27	1						31
6					4	21						25
7						4	8					12
8								1				1
9									1			1
10												
Omit		1	1	1		4	1				4	12
Tot.		6	20	24	31	30	9	1	1		4	126
Agreement between readings = 77%												

Table A2. Comparison of ages from 2 independent readings by L. Brown of otoliths from the second quarter commercial fishery.

Second reading \ First reading	1	2	3	4	5	6	7	8	9	10	Omit	Tot.
1												
2		7										7
3		1	17	1								19
4			4	24	1						1	30
5				2	13	1						16
6					1	27	1					29
7						1	9					10
8							1	9				10
9										1		1
10										1		1
Omit				1		1		1		1	8	12
Tot.		8	21	28	15	30	11	10		3	9	135
Agreement between readings = 85%												